Reconsidering The Impact of Environment on Long-Run Growth When Pollution Influences Health and Agents Have Finite-Lifetime

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Summary

Using an overlapping generation model à la Blanchard (1985) with human capital accumulation, this article demonstrates that the influence of environment on optimal growth in the long-run may be explained by the detrimental effect of pollution on life expectancy. It also shows that, in such a case, greener preferences are growth- and welfare-improving even if the ability of the agents to learn is independent to pollution and utility is additively separable. Finally, it establishes that it is possible to implement a win-win environmental policy.

Keywords: Growth, Environment, Overlapping Generations, Human Capital, Health

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1 Introduction

Does environment affect long term growth? Do environmental issues modify the time devoted to education? Is it possible to implement a win-win environmental policy? Over the last decade, some answers have been offered to thoses questions, at least partly. Nevertheless, their relevance remains topical, especially face to the unbridled industrialization of an economy such as China which challenges the worldwide efforts for a cleaner environment.

The purpose of this article is to re-examine the link between environment and growth focusing on the influence of pollution on health. It argues that the effects of pollution on life expectancy may explain by themselves the influence of environment on optimal growth, conversely to some previous theoretical works which assumed that the influence of environment on health leads to a direct detrimental impact of pollution on the educational activities.

In their investigations of the role of environment on long-term growth, some theoretical papers emphasized the impact of pollution on health. In dynamic models where the engine of growth is human capital accumulation, some of them argued that, by affecting health, pollution has a direct impact on long-term performances because it reduces the ability to learn (Gradus and Smulders (1993), van Ewijk and van Wijnbergen (1995), Vellinga (1999), Vellinga and Withagen (2001)). They also demonstrated that environment does not influence long-term accumulation of human capital if this direct impact of pollution on education is not taken into account. Even if the link between pollution and education sounds logical, two criticisms may be emphasized concerning their analysis. First, they did not model explicitly neither the influence of pollution on health (although it is the key mechanism), nor the way by which worse health may alter the ability to educate. Pollution is broadly introduced in the education sector as a simple component of the human capital depreciation (Gradus and Smulders (1993)) or as a variable which influences the productivity of education activities (van Ewijk and van Wijnbergen (1995)). Microfoundations would be required to clarify the underlying mechanisms. Second, the impact of pollution on health is well-documented (see below) and it is unmistakable that health affects positively growth. [1] Nevertheless this relation appears bi-directional and while the influence of education on health has been empirically established (see Grossman and Kaestner (1997)), there is a lack of empirical works on the causality between health and education (see Ding et al. (2005)). [2]

Conversely, the influence of pollution on life expectancy – used as a proxy of health –, is well-documented, especially for air pollution. For instance, Bell and Davis (2001) and Davis (2002) demonstrate that, during the London smog in 1952, the major part of the deaths was due to pollution and that this event has effects not only in short term but also in long-term. Several others studies highlight that air pollution has detrimental long-term effects, even at relatively low level: Kunzli and al. (2000) calculate the net impact of pollution tied with transport in Europe, Brunekreef and Holgate (2002) survey works on the influence of the particulate matter, Pope and al. (2002) find an impact on lung cancers and cardiopulmonary mortality, Evans and Smith (2005) show current and long-term effects of particulates on heart attacks and angina, Chay and Greenstone (2003) investigate air pollution and infant mortality during recession. [3] Other authors study the impact of air pollution on health for cities (Daniels and al. (2000), Dominici et al. (2000), Dominici et al. (2002)), Peng and al. (2002), Reshetin and Kazazyan (2004)).

So, this article aims at investigating the impact of pollution on life expectancy as the main channel of transmission of the relation between environment, health and growth, rather than assuming a direct detrimental effect of pollution on the ability to learn. In this purpose, we model explicitly the link between pollution and public health and its impact on the lifetime of the agents, assuming none direct impact of environment on schooling. We use an overlapping generations model à la Blanchard (1985) with environmental concerns. Long-run growth is driven by human capital accumulation à la Lucas (1988) and the lifetime of agents depends on public health which is influenced negatively by the level of pollution and positively by public health expenditures.

Our results are threefold. First, although individual education is not affected by environment we demonstrate that pollution has always a negative impact on optimal growth. Indeed, the accumulation of human capital at aggregate level is reduced by the loss of knowledge due to the vanishing of the dying generation. And the frequency at which a cohort vanishes depends on its life expectancy which is influenced by public health. When pollution is higher in the economy, despite the increase in public sanitary health expenditures, public health diminishes and the lifetime of agents as well. The vanishing of dying generations is more frequent and so the accumulation of human capital at aggregate level is lowered. Furthermore, the time devoted to education in the long-run is influenced by pollution according to the value of the intertemporal elasticity of substitution of the consumption. When this elasticity is lower than unity, a higher level of pollution increases the time devoted to education. The social planner wants to smooth the consumption over time and she has the desire to compensate the detrimental effect of more pollution on their utility by increasing consumption in the future. Therefore she invests more in human capital accumulation.

Second, conversely to Vellinga (1999), we demonstrate that environmental care influences positively the level of pollution and the rate of growth in the long-run, although preferences are additively separable and the individual accumulation of human capital is not affected by pollution. Furthermore, when agents have an intertemporal elasticity of substitution of the consumption lower than unity, greener preferences lead to a decrease of the time allocated to education while growth rate increases. We also establish that the growth-improving effect of greener preferences is always associated with a higher social welfare.

Finally, studying the decentralized equilibrium of the economy, we demonstrate that it is possible to implement a win-win environmental policy.

The article is build as follows. Section 2 gives the basic framework of our model. Section 3 formalizes the link between pollution, health and the probability of death. Section 4 investigates the balanced growth path (BGP) equilibrium of the centralized economy. Section 5 examines the impact of environmental care on the optimal growth in the long-run. Section 6 deals with environmental policy in a decentralized equilibrium and section 7 concludes.

2 The Economy's structure

Let's consider a Blanchard (1985) overlapping generations model with human capital accumulation and environmental concerns. Time is continuous. Each individual born at time s faces a constant probability of death per unit of time $\lambda_s \geq 0$. So her life expectancy is $1/\lambda_s$. When λ_s increases, the life span decreases. At time s, a cohort of size λ_s is born. This cohort has a size equal to $\lambda_s e^{-\lambda_s(t-s)}$ at time t. The constant population is equal to $\int_{-\infty}^{t} \lambda_s e^{-\lambda_s(t-s)} ds$ at time t. There are insurance companies and there is no bequest motive.

Conversely to Blanchard (1985), we assume that the probability of death for an agent born at time s depends negatively on the public health in the economy when he is born ε_s. To simplify we pose $\lambda_s = \varepsilon_s^{-1}$.

The expected utility function in period t of an agent born at time $s \leq t$ is of the following form:

$$\int_t^{\infty} U\left(c_{s,\iota}, \mathcal{P}_\iota\right) e^{-(\rho+\lambda_s)(\iota-t)} d\iota \tag{1}$$

with

$$U\left(c_{s,\iota}, \mathcal{P}_\iota\right) = \begin{cases} \dfrac{\left[c_{s,\iota}\mathcal{P}_\iota^{-\phi}\right]^{1-1/\sigma} - 1}{1-1/\sigma} & \sigma \neq 1, \\ \ln c_{s,\iota} - \phi \ln \mathcal{P}_\iota & \sigma = 1, \end{cases} \tag{2}$$

where $c_{s,\iota}$ denotes consumption in period ι of an agent born at time s, $\rho \geq 0$ is the rate of time preference, $\mathcal{P}_\iota$ is the net pollution flow and ϕ measures the weight in utility attached to environment, that is environmental care. σ is the elasticity of intertemporal substitution.

The representative agent can increase his stock of human capital by devoting time to schooling, according to Lucas (1988):

$$\dot{h}_{s,t} = B\left[1 - u_{s,t}\right] h_{s,t} \tag{3}$$

where B is the efficiency of schooling activities, $u_{s,t} \in [0,1]$ is the part of human capital allocated to productive activities at time t for the generation born at s and $h_{s,t}$ is the stock of human capital at time t of an individual born at time s. Note that no assumption is made about the influence of pollution on individual human capital accumulation. [4]

Due to the simple demographic structure all individual variables are additive across individuals. So the aggregate consumption equals

$$C_t = \int_{-\infty}^{t} c_{s,t}\lambda_s e^{-\lambda_s(t-s)} ds,$$

the aggregate human capital is

$$H_t = \int_{-\infty}^{t} h_{s,t}\lambda_s e^{-\lambda_s(t-s)} ds, \tag{4}$$

and the quantity of the aggregate stock of human capital used in production equals $H_{y,t} = \int_{-\infty}^{t} u_{s,t} h_{s,t} \lambda_s e^{-\lambda_s (t-s)} ds$.

The productive sector is competitive. The aggregate production function is defined by:

$$Y_t = K_t^{\alpha} H_{y,t}^{1-\alpha}, \qquad 0 < \alpha < 1 \tag{5}$$

with Y_t is the aggregate output and K_t is the aggregate stock of physical capital.

Finally, we assume that an amount G_t of final goods is used by the government to publicly provide health services G_t. This amount represents a part θ of the aggregate final output.

3 Ecology, health and lifetime

Following Gradus and Smulders (1993), pollution flow is assumed to increase with the stock of physical capital K and reduces with abatement activities A:

$$\mathcal{P}_t = \left[\frac{K_t}{A_t}\right]^{\gamma}, \qquad \gamma > 0 \tag{6}$$

Abatement activities use final output so the final market clearing condition is:

$$(1-\theta)Y_t = C_t + \dot{K}_t + \xi A_t \tag{7}$$

with $\xi > 0$.

Public health ε_s at time s is increasing with the expenditures on health related to GDP [5] and decreasing with the net flow of pollution $\mathcal{P}$. So we note $\varepsilon_s = \beta\theta/(\delta \mathcal{P}_s^{\psi})$, where $\beta > 0$ is the productivity of the health sector, δ is a positive parameter and ψ captures the impact of pollution on public health "depreciation". [6] Since the lifetime of an agent born at time s depends negatively on public health ($\lambda_s = \varepsilon_s^{-1}$), we have

$$\lambda_s = \frac{\delta \mathcal{P}^{\psi}}{\beta\theta} \equiv \lambda \tag{8}$$

Along the balanced growth path (BGP), the net flow of pollution must be constant because the environmental quality is constant. So public health and therefore the probability of death are constant and equal for all individuals.

4 Optimal growth and pollution along the BGP

In this section we investigate the influence of environment on the optimal growth in the long-run. From (7), it is straightforward that K, A, Y, C evolve at the same endogenous rate $g^{\star}$ than H the aggregate human capital, in the long run.

If we assume that all individuals allocate the same effort u_t to schooling, differentiating (4) with respect to time, and defining $h_{t,t}$ the human capital of an agent born at the current time t, we obtain the expression of the aggregate accumulation of human capital:

$$\dot{H}_t = B\left[1 - u_t\right] H_t - \left[\lambda H_t - \lambda h_{t,t}\right]$$

The last term into brackets in the RHS of the equation captures the fact that a part λ of the alive generations disappears at each date reducing growth by λH and that a new cohort of size λ appears, adding $\lambda h_{t,t}$ to growth. Actually $h_{t,t}$ is the human capital inherited from the dying generation. We assume that it is a constant part of the aggregate level of human capital such that $h_{t,t} = \eta H_t$ with $\eta \in [0, 1]$. So aggregate human capital accumulation is given by

$$\dot{H}_t = B\left[1 - u_t\right] H_t - (1 - \eta)\lambda H_t \tag{9}$$

where $(1 - \eta)\lambda H_t$ is the loss of human capital due to the vanishing of dying generation net from the intergenerational transmission of human capital.

Except when $\eta = 1$ (complete intergenerational transmission of knowledge), this loss is always positive. So, the probability of death λ, which is also the inverse of the lifetime of agents, contributes to long-run aggregate growth. A higher probability of death means a higher frequency at which a cohort vanishes so a greater net loss. It reduces the human capital accumulation for a given effort of education u.

Because the probability of death is positively determined by the flow of pollution [equation (8)], environment influences negatively accumulation of human capital at the aggregate level although it has no impact on the ability to learn.

As shown by Calvo and Obstfeld (1988), the aggregate planning problem reduces to the Cass-Koopmans-Ramsey problem of optimal allocation over time with a single representative infinitely lived individual (see appendix A). That is:

$$\begin{array}{rl} \max_{C_t,u_t,A_t,K_t,H_t,\theta_t} & \displaystyle\int_0^{\infty} U\left(C_t, \mathcal{P}\right) e^{-\rho t} dt \\ \text{s.t.} & \dot{K}_t = (1-\theta) K_t^{\alpha} [u_t H_t]^{1-\alpha} - C_t - \xi A_t \\ & \dot{H}_t = B[1-u_t] H_t - \lambda(1-\eta) H_t \\ & \mathcal{P} = \left[\dfrac{K_t}{A_t}\right]^{\gamma} \\ & \lambda = \dfrac{\delta \mathcal{P}^{\psi}}{\beta\theta}, \end{array} \tag{10}$$

with

$$U\left(C_t, \mathcal{P}\right) = \begin{cases} \dfrac{[C_t \mathcal{P}^{-\phi}]^{1-1/\sigma} - 1}{1-1/\sigma} & \sigma \neq 1, \\ \ln C_t - \phi \ln \mathcal{P} & \sigma = 1, \end{cases} \tag{11}$$

The resolution of this program gives the optimal allocation of human capital to production

$$u^{\star} = \frac{\rho}{B} + (1-\sigma) \frac{B - \Lambda(\mathcal{P}^{\star})(1-\eta)}{B}, \qquad \forall\, \sigma \tag{12}$$

where $\mathcal{P}^{\star}$ is the value of the pollution flow in the long run and $\Lambda(\cdot)$ is an increasing function (see appendix B).

The influence of pollution on $u^\star$ depends on the value of the intertemporal elasticity of substitution. Since $\Lambda(\mathcal{P}^\star)$ is positively infuenced by the BGP level of pollution, when $\sigma < 1$ pollution increases the investment in education $(1-u^\star)$. Indeed, for low values of the intertemporal elasticity of substitution, the social planner wants to smooth her utility over time. If $\mathcal{P}^\star$ is higher, she anticipates a lower intertemporal utility, therefore she wants to increase her consumption in the future to compensate the detrimental effect of a higher $\mathcal{P}^\star$. She increases her investment, especially her investment in human capital. The share of labor time devoted to production $(u^\star)$ decreases. When $\sigma > 1$, the social planner wants to compensate the current loss of utility due to more pollution by increasing her current consumption to the expense of savings and investment: $u^\star$ increases.

Finally, the optimal rate of growth along the BGP is given by

$$g^\star = \sigma B - \rho - \sigma\Lambda(\mathcal{P}^\star)(1-\eta)$$

So, it is negatively influenced by the net flow of pollution whatever the value of the intertemporal elasticity of substitution of consumption.

5 Environmental care and long-run growth

Do greener preferences lead to a higher or a lower optimal growth in the long-run? Due to the complexity of the expressions of $\mathcal{P}^\star$ (see appendix B), we use numerical simulations to answer this question. We calibrate the model to obtain realistic values of the growth rate of GDP and the probability of death for the US economy. From the *World Development Indicators 2004* by the World Bank, in the US economy, the death rate was 85 per 1000 in 2002 (so λ must be close to this value) and the growth rate was 3.3% during the period 1990-2002. Furthermore the part of health expenditures in GDP was 14% in 2002. So we adjust other variables to obtain such values for our benchmark case.

Table 1 summaries the benchmark parameters value and Table 2 summaries the exercise of comparative statics for log utility.

ϕ	α	ξ	η	δ	ψ	β	ρ	B	γ
0.01	1/3	0.001	0.75	0.16	1	0.1	0.05	0.11	0.5

Table 1. Benchmark parameters values

	Benchmark	$\phi = 0.005$	$\phi = 0.1$	$B = 0.15$	$\xi = 0.01$
g	3.85%	3.84%	4.02%	8.00%	2.70%
$\mathcal{P}$	0.1196	0.1206	0.1033	0.1051	0.2521
λ	0.0859	0.0863	0.0792	0.0799	0.1320
u	0.4545	0.4545	0.4545	1/3	0.4545
Y/K	0.6114	0.6072	0.6973	0.8382	1.0118
C/K	0.3668	0.3644	0.4178	0.4913	0.5184
H/K	1.0518	1.041	1.2809	2.3022	.2392
A/Y	0.1143	0.1132	0.1344	0.1081	0.1143
θ	0.2227	0.2235	0.2088	0.2103	0.3056
W	15.82	15.58	20.62	32.45	11.08

Table 2. Numerical estimations for log utility along the BGP

The third and fourth columns of table 2 highlight that, environemental care influences the long-term growth rate, conversely to Vellinga (1999) who demonstrated that growth is not influenced by environment when pollution does not affect the ablity of individual to educate and preferences are additive. When ϕ increases (fourth column), the weight of the net flow of pollution increases in utility. So the government decides to increase their abatement expenditures to the detriment of physical capital. This leads to a decrease in the net flow of pollution. So public health becomes higher and the probability of death reduces, increasing the aggregate human capital accumulation although the time allocated to education remains unchanged. The BGP growth rate rises, as well as the ratio H/K, Y/K, C/K.

The fifth column shows that an increase in the effectivness of education (B) incites the social planner to allocate more ressources to education: $u^\star$ drops. This leads to a decrease in the rate of returns to physical capital. So production becomes less capitalistic in terms of physical capital and pollution reduces. A lower level of pollution leads to a higher public health and so a lower probability of death. This contributes, with the increase in B, to a great rise of the long-term rate of growth. The sixth column emphasizes that a deterioration in the technology of abatement (ξ the part of output used to abatement increases) leads to higher pollution. This means a greater probability of death and so a lower long-term rate of growth. The crowding-out effect of abatement activities is higher.

Table 2 also reports the values of the social welfare with respect to changes in the parameters value. [7] A higher environmental care leads to a greater social welfare due to the reduction in the net flow of pollution and the increase in the growth rate of output. In the same way, an education sector more efficient (B is higher) leads to a higher growth rate and a lower level of net pollution and so implies a greater social welfare (fifth column).

Using parameter values from Table 1, we also simulate the economy for different values of the intertemporal elasticity of substitution σ.

	Benchmark	$\phi = 0.005$	$\phi = 0.1$	$B = 0.15$	$\xi = 0.01$
g	1.44%	1.43%	1.59%	4.51%	0.387%
$\mathcal{P}$	0.1470	0.1485	0.1257	0.1370	0.3219
λ	0.0966	0.0971	0.0884	0.0928	0.1527
u	0.6497	0.6494	0.6543	0.5447	0.6178
Y/K	0.5238	0.5206	0.5872	0.7073	0.7621
C/K	0.3232	0.3211	0.3619	0.42	0.3921
H/K	0.5837	0.583	0.6878	1.0921	1.0768
A/Y	0.1121	0.1112	0.1291	0.2965	0.1431
W	5.60	5.39	9.38	14.17	1.73

Table 3. Numerical estimations for $\sigma = 0.75$

	Benchmark	$\phi = 0.005$	$\phi = 0.1$	$B = 0.15$	$\xi = 0.01$
g	7.32%	7.31%	7.48%	13.72%	6.62%
$\mathcal{P}$	0.0645	.0649	0.0553	0.01400	0.1114
λ	0.0610	0.0613	0.0561	0.0271	0.0825
u	0.1961	0.1963	0.1928	0.0469	0.2108
Y/K	1.2111	1.1986	1.5064	17.154	3.4267
C/K	0.7075	0.7000	0.8822	10.5116	1.8297
H/K	6.7954	6.6836	9.5888	1515.93	30.03
A/Y	0.1864	0.1853	0.2071	0.2965	0.2309
W	45.022	44.53	54.79	149.01	38.74

Table 4. Numerical estimations for $\sigma = 1.3$

Whatever the value of σ our results remain valid: an increase in the environment care leads to a lower value of pollution while the rate of growth is higher, in the long-run. When $\sigma < 1$, a greater ϕ leads to a higher allocation of human capital to production for the reasons explained before, while the long-term rate of growth increases.

We also report the values of the social welfare. It improves with greener preferences and a higher efficiency of schooling activities.

6 Market equilibrium and environmental policy

This section investigates the effect of a pollution tax on the growth rate of the decentralized equilibrium.

In this economy, there are two externalities. The first one comes from the detrimental effect of pollution on utility. The second one arises because public health is negatively influenced by pollution. In a decentralized economy, final producers do not internalize the negative impact of their pollution flow neither on utility nor on public health. So they may pollute too much with respect to the optimal equilibrium and there is a room for environmental policy.

Let's consider the decentralized economy. Households face the following budget constraint:

$$\dot{a}_{s,\iota} = [r_\iota + \lambda]\, a_{s,\iota} + u_{s,\iota} h_{s,\iota} w_\iota - c_{s,\iota} + T_\iota \tag{13}$$

where $a_{s,\iota}$ is the financial wealth in period ι, ω_ι represents the wage rate per effective unit of human capital $u_{s,\iota} h_{s,\iota}$, and T_ι denotes transfers from the public sector.

The representative agents choose the time path for $c_{s,\iota}$ and his working time $u_{s,\iota}$ by maximizing (1) subject to (3) and (13). It gives the consumption at time t of an agent born at time s:

$$c_{s,t} = \Delta\, [a_{s,t} + \omega_{s,t}] \tag{14}$$

where $\omega_{s,t} \equiv \int_t^\infty [u_{s,\iota} h_{s,\iota} w_\iota]\, e^{\int_t^\iota [r_\varsigma + \lambda] d\varsigma} d\iota$ is the present value of lifetime earning and $\Delta_t \equiv (1-\sigma) r_t + \sigma\rho + \lambda$. [8] It also gives:

$$\frac{\dot{w}_t}{w_t} + B - \lambda = r_t \tag{15}$$

The rate of returns on human capital (left-hand side) is equal to the rate of returns of physical capital, the interest rate (right-hand side). When the probability of death diminishes, the rate of returns to education increases, because the life span of agents increases.

The aggregate consumption equals

$$C_t = \int_{-\infty}^t c_{s,t} \lambda e^{-\lambda(t-s)} ds = \Delta_t\, [K_t + \Omega_t] \tag{16}$$

with $\Omega_t \equiv \int_{-\infty}^t [\omega_{s,t}]\, \lambda e^{-\lambda(t-s)} ds$, and the aggregate stock of physical capital is defined by

$$K_t = \int_{-\infty}^t a_{s,t} \lambda e^{-\lambda(t-s)} ds \tag{17}$$

The government implements an environmental policy which consists in taxing the net flow of pollution by firms and transfering the fruit of the taxes to households in a lump-sum fashion. [9]

In the decentralized economy, firms pay a pollution tax on their net pollution $\mathcal{P}_t$ and they choose their abatement activities A_t (whose cost equals ξA_t) and the amount of factors which maximize their profits $\pi_t = Y_t - r_t K_t - w_t H_{y,t} - \vartheta_t \mathcal{P}_t - \xi A_t$ where ϑ_t is the pollution tax rate. So they pay each production factor at its marginal productivity:

$$r_t = \alpha \frac{Y_t}{K_t} - \vartheta_t \gamma \frac{\mathcal{P}_t}{K_t} \tag{18}$$

$$w_t = (1-\alpha) \frac{Y_t}{H_{y,t}} \tag{19}$$

$$\xi A_t = \vartheta_t \gamma \mathcal{P}_t \tag{20}$$

The pollution tax increases over time to incite firms to increase abatement activities to limit pollution which rises with the physical capital stock.

From equations (6) and (20), we have $\mathcal{P}_t = \left[\chi \frac{\vartheta_t}{K_t}\right]^{-\gamma/(1+\gamma)}$ with $\chi \equiv \gamma/\xi$, and therefore the probability of death is given by:

$$\lambda = \frac{\delta \left[\chi \tau\right]^{\frac{-\gamma\psi}{1+\gamma}}}{\beta\theta} \equiv \mathcal{L}(\underset{-}{\tau}) \tag{21}$$

with $\tau \equiv \vartheta_t / K_t$ is the environmental tax normalized by the physical capital, constant along the balanced growth path. Following Oueslati (2002), we assume that τ is fixed by the government and therefore has no a transitional dynamics. So $\mathcal{P}$ and λ are independant of time.

Differentiating (16) with respect to time and using the expression of dK_t/dt and $d\Omega_t/dt$ gives:

$$\dot{C}_t = \sigma \left[r_t - \rho\right] C_t - \mathcal{L}(\tau) \Delta_t K_t \tag{22}$$

Finally, using (15) and (19), we obtain:

$$\dot{u}_t / u_t = \dot{K}_t / K_t - \dot{H}_t / H_t - \alpha^{-1} \left[r_t + \mathcal{L}(\tau) - B\right] \tag{23}$$

Using previous results, we can write the dynamics of the model as:

$$\begin{aligned} \dot{x}/x = &\ [\alpha\sigma - 1]\,(bu)^{1-\alpha} - \rho - \mathcal{L}(\tau)\left[(1-\sigma)\alpha(bu)^{1-\alpha} + \sigma\rho + \mathcal{L}(\tau)\right]x^{-1} + x \\ \dot{b}/b = &\ B\,[1-u] - (1-\eta)\mathcal{L}(\tau) - (bu)^{1-\alpha} + x + \xi\,[\chi\tau]^{1/(1+\gamma)} \\ \dot{u}/u = &\ \alpha^{-1}\,[B - \mathcal{L}(\tau)] - (bu)^{1-\alpha} + \alpha^{-1}\xi\,[\chi\tau]^{1/(1+\gamma)} - \dot{b}/b \end{aligned} \tag{24}$$

with $\mathcal{L}(\tau) \equiv \frac{\delta}{\beta\theta}\,[\chi\tau]^{\frac{-\gamma\psi}{1+\gamma}}$

Along the balanced growth path, C, K, H and Y evolve at the same rate and the allocation of human capital accross sectors are constant: $\dot{x} = \dot{b} = \dot{u} = 0$. So, from the last equation of system (24):

$$\alpha\,(b_c^\star u_c^\star)^{1-\alpha} - \xi\,[\chi\tau]^{\frac{1}{1+\gamma}} = B - \mathcal{L}(\tau),$$

where $b_c^\star$ and $u_c^\star$ are respectively the BGP value of u and b in the decentralized economy. The private returns to physical capital accumulation equals the private returns to education.

Substracting the first and the second equation of (24) evaluated to the BGP gives the expression of x. Equalizing to the expression of x given by the second equation of (24) evaluated to the BGP enables to express the implicit value of $u_c^\star$:

$$Bu_c^\star + \left[\alpha^{-1} - 1\right]B - \mathcal{L}(\tau)\left[\alpha^{-1} + \eta - 1\right] + \left(\alpha^{-1} - 1\right)\xi\,[\chi\tau]^{\frac{1}{1+\gamma}}$$

$$=$$

$$\mathcal{L}(\tau)\frac{\sigma\rho + \sigma\mathcal{L}(\tau) + (1-\sigma)(B + \xi\,[\chi\tau]^{\frac{1}{1+\gamma}})}{B(\sigma - 1 + u_c^\star) + (1-\sigma-\eta)\mathcal{L}(\tau) - \rho + (\sigma-1)\xi\,[\chi\tau]^{\frac{1}{1+\gamma}}}$$

In both cases, the left-hand side is a positive increasing function of $u_c^\star$ and the right-hand side is a positive decreasing function of $u_c^\star$. So there exists a unique value for $u_c^\star$ along the BGP. The LHS is an increasing function of τ while the RHS is a decreasing function of τ when $\sigma \geq 1$. So, for $\sigma \geq 1$, $u_c^\star$ decreases with τ. [10]

Finally, the growth of the decentralized economy along the BGP is:

$$g_c^{\star} = B\left[1 - u_c^{\star}(\tau)\right] - (1-\eta)\left[\chi\tau\right]^{\frac{-\gamma\psi}{1+\gamma}}.$$

It clearly appears that the BGP rate of growth in the decentralized economy increases with τ when $\sigma \geq 1$: environmental policy has a positive impact because it reduces pollution, so it increases health and the returns education, and therefore it fosters human capital accumulation. It means that it is possible to implement a win-win environmental policy in our framework.

7 Concluding remarks

The purpose of this article was to investigate the link between environment and growth focusing on the impact of pollution on health. Conversely to some previous works, we did not assume that the effect of environment on health leads to a direct impact of pollution on education. Rather, we argued – and we demonstrated – that the detrimental influence of pollution on life expectancy is, by itself, a channel of transmission between environment, health and optimal growth in the long-run.

We used an overlapping generations model à la Blanchard (1985) assuming that the probability of death depends negatively of public health and that public health is influenced negatively by pollution and positively by public health expenditures. We demonstrated that pollution reduces the optimal rate of growth while individual accumulation of human capital is not influenced by environment. Deteriorating public health, pollution reduces the probability of death in the economy, even if the social planner increases health expenditures in response to the lower quality of environment. Therefore the replacement of generations becomes more frequent and the loss of knowledge due to this replacement grows, reducing the aggregate human capital accumulation and the growth rate of the economy.

Conversely to Vellinga (1999), we also demonstrated that greener preferences affect the optimal rate of growth in the long-term, although individual accumulation of human capital is independant of environment and preferences are separable. Furthermore we showed that the time devoted to education is influenced by the level of pollution when the intertemporal elasticity of substitution of the consumption is not unity. For an elasticity lower than one, greener preferences lead to less investment in education but to a higher growth rate. We also established that in all cases, greener preferences are growth- and welfare-improving, because it leads to a lower level of pollution, that is a lower probability of death which limits the replacement of generations and therefore fosters growth. Finally, by studying the equilibrium of the decentralized economy, we demonstrated that it is possible in our framework to implement a win-win environmental policy.

The simplicity of our framework calls for further theoretical investigations especially to enrich the function of public health. It also offers another tools for public authorities to curve pollution and its detrimental effects on growth. Tools which must be studied more precisely. This could give some directions for further research.

Notes

1. See López-Casanovas et al. (2005) for theoretical analysis and policy implications. See Bloom and Canning (2005) and references herein for empirical evidences.

2. Existing studies on the causality between health and education only examinate the effect of child health on schooling performances in special cases: structural health problems like diseases or poor nutrition in developing countries (Mayer-Foulkes (2005)), obsesity and depression in developed countries (see references in Ding et al. (2005)).

3. See Koop and Tole (2004) for a discussion about the statistical problems to evaluate the impact of air pollution on mortality rate.

4. Furthermore, we do not assume that health positively influences the individual productivity of schooling, even if it sounds logical. The reason is that, as shown in the following (section 3), health depends on the level of pollution and one of the purpose of the paper is to demonstrate that pollution affects growth even if it does not influence directly or indirectly individual human capital accumulation. Assuming that B depends on health would be similar to the assumption made by Gradus and Smulders (1993) and would not give more insights.

5. We follow Aisa and Pueyo (2004) and Currais and Rivera (1999).

6. The intuition is that the temporal evolution of public health at time s is described by:

$$\dot{\varepsilon}_s = \beta \frac{G_s}{Y_s} - \delta \mathcal{P}_s^{\psi} \varepsilon_s,$$

where $\delta \mathcal{P}_s^{\psi}$ is the depreciation rate of public health. In the long-run, public health is constant, so $\dot{\varepsilon} = 0$ and we obtain $\varepsilon = \frac{\beta\theta}{\delta \mathcal{P}^{\psi}}$.

7. Social welfare is computed using the fact that the economy begins along the BGP. So $C_t = C_0 e^{g^\star t}$ with $C_0 = 1$:

$$W = \int_0^{\infty} \ln[e^{g^\star t} \mathcal{P}^{\star - \phi}] e^{-\rho t} dt = \frac{g^\star/\rho - \phi \ln \mathcal{P}^\star}{\rho}, \qquad \sigma = 1,$$

$$W = \int_0^{\infty} \frac{[e^{g^\star t} \mathcal{P}^{-\phi}]^{1-1/\sigma} - 1}{1 - 1/\sigma} e^{-\rho t} dt = \frac{\mathcal{P}^{\star - \phi(1-1/\sigma)} \left[\rho - (1-1/\sigma) g^\star\right]^{-1} - 1/\rho}{1 - 1/\sigma}, \qquad \sigma \neq 1$$

8. See Blanchard (1985) for a demonstration.

9. We assume that the government fixes exogenously θ. Assuming that it chooses the optimal level of θ given by the equation (B.16, appendix B) does not modify the qualitative results.

10. For $\sigma < 1$, the impact of τ on $u_c^\star$ is not clear-cut. So we do not investigate this case.

Appendix

In this appendix we derive the program (10). In a first time, we follow Calvo and Obstfeld (1988) who demonstrate that the aggregate planning problem reduces to the Cass-Koopmans-Ramsey problem of optimal allocation over time with single representative infinitely-lived individual. After, we write the Hamiltonian of the program and we derive the BGP equilibrium of the centralized economy.

A The objective of the social planner

The social welfare function, at time $t = 0$ is the sum of two components. The first captures the expected utilities of agents from each of the generation to be born, measured from the moment of birth. The second captures expected utilities of agents from each of those generations currently alive, over the remainder of their lifetimes, measured from the time $t = 0$. The planner discount rate is equal to the pure time-preference ρ to avoid problems of time-consistency (see Calvo and Obstfeld (1988) for more details). So welfare at $t = 0$ is

$$W_0 = \int_0^\infty \left\{ \int_s^\infty \nu[c_{s,t}]\lambda e^{-(\rho+\lambda)(t-s)}dt \right\} e^{-\rho s}ds + \int_{-\infty}^0 \left\{ \int_0^\infty \nu[c_{s,t}]e^{-\rho t}\lambda e^{-\lambda(t-s)}dt \right\} ds \quad \text{(A.1)}$$

Note that the second term in the RHS is discounted by the planner at time 0, so it is written as $\int_{-\infty}^0 \left\{ \int_0^\infty \nu[c_{s,t}]e^{-\rho(t-0)}\lambda e^{-\lambda(t-s)}dt \right\} e^{-\rho 0}ds$.

Changing variables from vintage s to age $n = t - s$, we can rewrite W_0

$$W_0 = \int_0^\infty \left\{ \int_0^\infty \nu[c_{t-n,t}]\lambda e^{-\lambda n}dn \right\} e^{-\rho t}dt \quad \text{(A.2)}$$

Note that to keep things simple, we assumed that the centralized economy begins at the BGP equilibrium. It enables to have λ independent to n (see section 3).

The social planner maximizes (A.2) subjects to the constraint (6), (7), (8) and (9) with $C_t = \int_0^\infty c_{t-n,t}\lambda e^{-\lambda n}dn$. This problem may be decomposed in two stages. First the planner solves a static problem: given a level of aggregate consumption C_t, he allocates this level of consumption across individual to maximize the time-t instantaneous utility flow $\int_0^\infty \nu[c_{t-n,t}]\lambda e^{-\lambda n}dn$. Second, he solves a dynamic problem, choosing the aggregate consumption path $\{C_t\}_{t=0}^\infty$ that maximizes (A.2) subject to (6), (7), (8) and (9).

If we define the indirect utility function:

$$V[C_t] = \max_{c_{t-n,t}{}_{n=0}^{\infty}} \int_0^\infty \nu[c_{t-n,t}]\lambda e^{-\lambda n}dn$$

subject to $\int_0^\infty c_{t-n,t}\lambda e^{-\lambda n}dn \leq C_t$, the planning problem becomes

$$\max W_0 = \int_0^\infty V[C_t]e^{-\rho t}dt$$

subject to (6), (7), (8) and (9).

Calvo and Obstfeld (1988) demonstrate that

$$V'[C_t] = \nu'[c_{t-n,t}] \tag{A.3}$$

at the optimum and that the necessary conditions for a static optimum are

$$\nu'[c_{t-n,t}] = \Pi_t \tag{A.4}$$

for all $n \in [0, \infty)$ with Π_t is a Lagrange multiplier. These conditions enable to find $V[C_t]$ knowing $\nu[c_{t-n,t}]$.

Let suppose that $\nu[c_{t-n,t}] \equiv \ln c_{t-n,t} - \phi \ln \mathcal{P}$. From (A.3), $V[C_t] = \Omega\left[\ln C_t - \phi \ln \mathcal{P}\right]$ with $1/c_{t-n,t} = \Omega/C_t$. (A.4) means that $c_{t-n,t} = c_t$ whatever n and so $C_t = \int_0^\infty c_{t-n,t}\lambda e^{-\lambda n}dn = c_t$. So $\Omega = C_t/c_t = 1$ and $V[C_t] \equiv [\ln C_t - \phi \ln \mathcal{P}]$. When $\nu[c_{t-n,t}] \equiv \dfrac{1}{1-1/\sigma}[c_{t-n,t}\mathcal{P}^{-\phi}]^{1-1/\sigma}$, with the same rational, we have $V[C_t] = \dfrac{1}{1-1/\sigma}[C_t\mathcal{P}^{-\phi}]^{1-1/\sigma}$.

B Derivation of the BGP equilibrium in the centralized economy

The Hamiltonian of the program (10), with $\sigma \neq 1$ is:

$$\mathcal{H} = \frac{1}{1-1/\sigma}\left\{\left[C\left(\frac{K}{A}\right)^{-\gamma\phi}\right]^{1-1/\sigma} - 1\right\} + \pi_1\left\{(1-\theta)K^{\alpha}[uH]^{1-\alpha} - C - \xi A\right\}$$
$$+ \pi_2\left\{B[1-u]H - \frac{\delta[K/A]^{\gamma\psi}}{\beta\theta}(1-\eta)H\right\} \quad \text{(B.1)}$$

The first order conditions give:

$$\frac{\partial\mathcal{H}}{\partial C} = 0 \quad \Rightarrow \quad C^{-1/\sigma}\left(\frac{K}{A}\right)^{-\gamma\phi(1-1/\sigma)} = \pi_1 \quad \text{(B.2)}$$

$$\frac{\partial\mathcal{H}}{\partial u} = 0 \quad \Rightarrow \quad \pi_1(1-\theta)(1-\alpha)K^{\alpha}(uH)^{-\alpha} = \pi_2 B \quad \text{(B.3)}$$

$$\frac{\partial\mathcal{H}}{\partial A} = 0 \quad \Rightarrow \quad \frac{\phi\gamma}{A}\left[\frac{K}{A}\right]^{-\gamma\phi(1-1/\sigma)} C^{1-1/\sigma} - \xi\pi_1 + \pi_2\lambda'_A(1-\eta)H = 0 \quad \text{(B.4)}$$

$$\frac{\partial\mathcal{H}}{\partial\theta} = 0 \quad \Rightarrow \quad \pi_1 K^{\alpha}(uH)^{1-\alpha} - \pi_2\frac{\lambda}{\theta}(1-\eta)H = 0 \quad \text{(B.5)}$$

$$\frac{\partial\mathcal{H}}{\partial K} = -\dot{\pi}_1 + \rho\pi_1 \quad \Rightarrow \quad \frac{-\phi\gamma}{K}\left[\frac{K}{A}\right]^{-\gamma\phi(1-1/\sigma)} C^{1-1/\sigma}$$
$$+ \pi_1\alpha(1-\theta)K^{\alpha-1}(uH)^{\alpha-1}$$
$$- \pi_2\lambda'_K(1-\eta)H = -\dot{\pi}_1 + \rho\pi_1 \quad \text{(B.6)}$$

$$\frac{\partial\mathcal{H}}{\partial H} = -\dot{\pi}_2 + \rho\pi_2 \quad \Rightarrow \quad \pi_1(1-\alpha)(1-\theta)K^{\alpha}(uH)^{-\alpha}u + \pi_2[B(1-u) - \lambda(1-\eta)] = -\dot{\pi}_2 + \rho\pi_2 \quad \text{(B.7)}$$

with $\lambda \equiv \frac{\delta[K/A]^{\gamma\psi}}{\beta\theta}$, $\lambda'_A = -\gamma\psi\frac{\lambda}{A}$ and $\lambda'_K = \gamma\psi\frac{\lambda}{K}$.

Using (B.3) and (B.7) gives:

$$\frac{\dot{\pi}_2}{\pi_2} = \rho - B + \lambda(1-\eta) \quad \text{(B.8)}$$

Extracting $-\phi\gamma$ in (B.4) and introducing it in (B.6), using (B.3) and simplifying, we obtain:

$$\frac{\dot{\pi}_1}{\pi_1} = \rho + \xi \left(\frac{A}{K}\right) - \alpha(1-\theta)K^{\alpha-1}(uH)^{1-\alpha} \tag{B.9}$$

We define $b \equiv H/K$, $x \equiv C/K$, and we use $\mathcal{P} = [K/A]^{\gamma}$. All these variables are constant along the BGP since H, K, A, C and Y evolves at the same growth rate (see equation 7). So we can express the dynamics of the economy by expressing the inter temporal evolution of these variables. It gives:

$$\frac{\dot{x}}{x} = (\sigma\alpha - 1)(1-\theta)(bu)^{1-\alpha} - \sigma\rho + x + (1-\sigma)\xi\mathcal{P}^{\star -1/\gamma} \tag{B.10}$$

$$\frac{\dot{b}}{b} = B(1-u) - \frac{\delta\mathcal{P}^{\psi}}{\beta\theta}(1-\eta) - (1-\theta)(bu)^{1-\alpha} + x + \xi\mathcal{P}^{-1/\gamma} \tag{B.11}$$

Differentiating (B.3) with respect to time, it comes:

$$\frac{\dot{u}}{u} = \alpha^{-1}\left(\frac{\dot{\pi}_1}{\pi_1} - \frac{\dot{\pi}_2}{\pi_2}\right) - \frac{\dot{b}}{b} \tag{B.12}$$

Along the BGP $\dot{u} = \dot{b} = \dot{x} = 0$. Therefore, (B.9), (B.8) and (B.12) give

$$\alpha(1-\theta)(b^{\star}u^{\star})^{1-\alpha} = B - \frac{\delta\mathcal{P}^{\star\psi}}{\beta\theta}(1-\eta) + \xi\mathcal{P}^{\star -1/\gamma} \tag{B.13}$$

that is the returns to the accumulation of physical capital equals the returns to accumulation of human capital. Subtracting (B.10), (B.11) and (B.12) estimated to the BGP, we obtain the value of the allocation of human capital to production in the long-run

$$u^{\star} = \frac{\rho}{B} + (1-\sigma)\frac{B - \lambda(1-\eta)}{B}. \tag{B.14}$$

Using (B.10) evaluated along the BGP gives

$$x^{\star} = \frac{1-\alpha\sigma}{\alpha}\left[B + \xi\mathcal{P}^{\star -1/\gamma} - \Lambda(\mathcal{P}^{\star})(1-\eta)\right] + \sigma\rho - (1-\sigma)\xi\mathcal{P}^{\star -1/\gamma} \tag{B.15}$$

Using (B.3), (B.5) and (B.14), we obtain a relation between $\theta^\star$ the part of health care expenditures and the net pollution flow along the BGP $\mathcal{P}^\star$:

$$\frac{\theta^{\star 2}}{(1-\theta^\star)} = \Omega \mathcal{P}^{\star\psi}$$

with $\Omega \equiv \frac{(1-\alpha)(1-\eta)\delta}{\beta\rho}$. So, the higher is the net flow of pollution in the long-run, the higher is the part of the public health care expenditures in GDP. Solving this relation gives

$$\theta^\star = \frac{-\Omega\mathcal{P}^{\star\psi} + \sqrt{\Omega^2\mathcal{P}^{\star 2\psi} + 4\Omega\mathcal{P}^{\star\psi}}}{2} \tag{B.16}$$

So, the proba of death along the BGP depends positively on the net flow of pollution:

$$\lambda^\star = \frac{\delta\mathcal{P}^{\star\psi}}{\beta\theta^\star} = \frac{2\delta}{\beta\left[-\Omega + \sqrt{\Omega^2 + 4\Omega/\mathcal{P}^{\star\psi}}\right]} \equiv \Lambda(\underset{+}{\mathcal{P}^\star})$$

Note that $\theta^\star$ is always lower than unity and that $\lim_{\mathcal{P}\to 0}\Lambda(\mathcal{P}^\star) = 0$ and $\lim_{\mathcal{P}^\star\to+\infty}\Lambda(\mathcal{P}^\star) = +\infty$.

Finally, using the value of $u^\star$ we see that the expression of the growth rate along the BGP depends negatively on the long-run flow of pollution:

$$g^\star = \sigma B - \rho - \sigma\Lambda(\mathcal{P}^\star)(1-\eta)$$

Using (B.3), (B.2) and (B.4), we can define $\mathcal{P}^\star$ as

$$\gamma\left(\frac{1-\alpha}{\alpha}\right)\left[\phi + \frac{(1-\eta)\Lambda(\mathcal{P}^\star)}{\rho}\right]\left[B + \mathcal{P}^{\star -1/\gamma} - (1-\eta)\Lambda(\mathcal{P}^\star)\right] + \gamma\phi\rho - \xi\mathcal{P}^{\star -1/\gamma} = 0 \tag{B.17}$$

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